Ambient Groundwater Quality of the Virgin River Basin: An ADEQ 1997 Baseline Study

I. Introduction

The Virgin River groundwater basin (VRGB), located in the remote northwest corner of Arizona (**Figure 1**) is a region of stunning natural scenery and a small, but rapidly growing population. The perennial Virgin River, which diagonally bisects the arid VRGB, enters from Utah where it then flows across 35 miles of the northwest corner of Arizona before exiting the state into Nevada (**Figure 2**).

In the northeast portion of the VRGB, the watercourse flows through the Virgin River Gorge, an area of spectacular geology admired by motorists traveling through Arizona on Interstate 15. The gorge separates the Paiute and Beaver Dam Mountains wilderness areas that are found in the basin. Southwest of the gorge is the broad Virgin Valley which contains small communities historically based upon irrigated agriculture. The valley has experienced recent residential growth that often consists of retirees drawn to the area by a mild climate and amenities offered by the nearby Nevada casino resorts.

The Arizona Department of Environmental Quality (ADEQ) conducted a regional groundwater quality study of the VRGB in 1997. This ADEQ factsheet is a summary of the more extensive, previously published ADEQ hydrology report available from the agency (1).

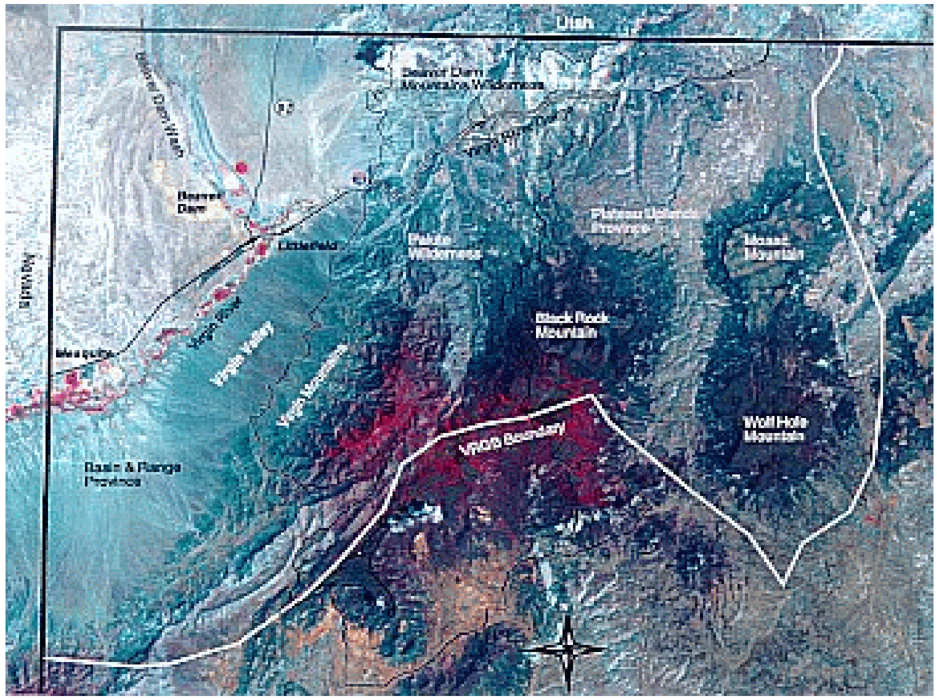

Figure 2. In this infra-red satellite image of the Virgin River basin (outlined in white), riparian vegetation, irrigated farmland, and, near mountain summits, juniper forest appear in crimson.

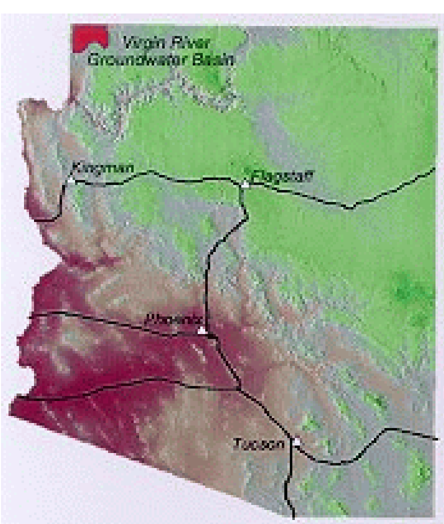

Figure 1. Location of the VRGB within Arizona.

II. Background

The VRGB encompasses more than 430 square miles in the Arizona Strip section of Mohave County (2). For this report, the VRGB consists of both hydrological boundaries (the Virgin Mountains and Beaver Dam Mountains to the east and south) and political boundaries (the Utah border to the north and the Nevada border to the west) (**Figure 2**).

Two major physiographic areas intersect within the VRGB. The Virgin River Gorge (**Figure 3**) is the demarcation between the Plateau Uplands Province in the northeast and the Basin and Range Lowlands Province in the southwest. Surface topography in the latter consists of sloping alluvial fans which extend from the surrounding rugged mountains to the valley floor. Precipitation averages seven inches annually, increasing markedly with elevation. Natural vegetation varies with topography and water availability. Salt cedar, cottonwood, and willow trees are found in river riparian areas; creosote bush, yucca, and Joshua trees grow in the valleys; and juniper forests are found at the highest mountain elevations.

The Virgin River is a major tributary of the Colorado River. From its headwaters in the Markagunt Plateau above Cedar City, Utah, the Virgin River flows through Zion National Park before eventually discharging into Lake Mead in Nevada. The river's largest tributary in Arizona is Beaver Dam Wash, which is perennial for approximately one mile above its juncture with the Virgin River (2). The Virgin River is called the *Pah Roose* meaning very muddy stream by the region's original inhabitants, the Paiute Indians. A free-flowing river until it reaches Lake Mead, it is characterized by high turbidity and salinity levels (2).

Most land within the VRGB is topographically rugged, remote country managed by the U.S. Bureau of Land Management. Small holdings of private land exist, especially in Virgin Valley. Some of these parcels contain densely settled residences utilizing septic systems for wastewater treatment. Communities found within the basin include Beaver Dam and Littlefield. Mesquite, Nevada and St. George, Utah are located nearby. Groundwater is the primary source for municipal, domestic, and livestock uses; however surface water is also used for irrigation.

III. Hydrogeologic Setting

Four VRGB aquifers were examined in this study (**Figure 4**). These include:

- Beaver Dam Wash (**BDW**) aquifer
- Littlefield (**LTL**) aquifer
- Virgin River alluvial (**VRA**)aquifer
- Virgin River basin (**VRB**) aquifer

The BDW aquifer consists of unconsolidated silt, sand, and gravel deposited between steep terraces created by the incision of Beaver Dam Wash (2). The LTL aquifer, located northeast of the town of Littlefield, is comprised of alluvial-fan deposits that rest on a limestone formation (2). The VRA aquifer consists of the floodplain and terrace alluvium southwest of Littlefield (2). The VRB aquifer is composed of the alluvial fan deposits of the Virgin Mountains south of the Virgin River.

IV. Methods of Investigation

The ADEQ Groundwater Monitoring Program, which is authorized by the legislative requirement in Arizona Revised Statute §49-225 to monitor the quality of the state's groundwater, conducted this study. To characterize regional groundwater quality, 38 sites were sampled for inorganic constituents. At selected sites, samples were also collected for radiochemistry (10 sites) and pesticide (3 sites) analyses.

Figure 3. The Virgin River and Interstate 15 intertwine through the Virgin River Gorge.

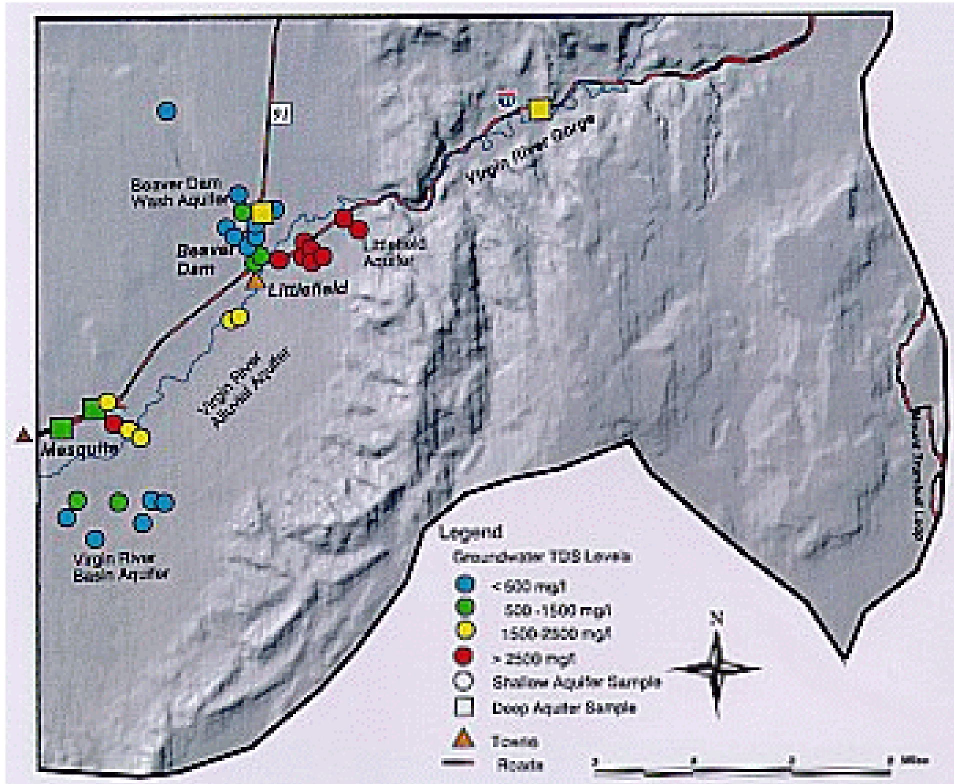

Figure 4. Total dissolved solids (TDS) concentrations are shown at 38 sampling sites. High TDS is the main limitation in using groundwater for domestic use in the VRGB.

The VRGB consists largely of rugged, undeveloped wilderness lands. As a result, groundwater sampling was concentrated in the Virgin Valley since most other basin areas have few, if any, wells (**Figure 4**). Sample sites were chosen according to a random selection process and stratified by aquifer.

Sampling protocol followed the ADEQ *Quality Assurance Project Plan* (3). Interpretation of the quality control data indicated that the effects of sampling equipment and laboratory procedures on the analytical results were not considered significant. The exception was potential antimony contamination acquired through impurities in filters during sample processing.

V. Water Quality Standards

The collected groundwater quality data was compared with federal Safe Drinking Water (SDW) quality standards (4). Primary Maximum Contaminant Levels (MCLs) are enforceable, health-based, water quality standards that public water systems must meet when suppling this resource to their customers. Primary MCLs are based on a lifetime daily consumption of two liters of water. Only 1 of the 38 sites sampled had parameter levels exceeding a Primary MCL. This exceedance involved gross alpha levels in a well tapping the LTL aquifer.

Secondary MCLs are unenforceable, aesthetics-based, water quality standards that are guidelines for public water systems (4). Water with Secondary MCL exceedances may be unpleasant to drink, but it is not considered to be a health concern. Of the 38 sites sampled, 25 had parameters exceeding a Secondary MCL. Secondary MCLs were exceeded for the following parameters: total dissolved solids or TDS (25 sites), sulfate (17 sites), chloride (15 sites), iron (7 sites), manganese (5 sites), and pH (1 site). Most Secondary MCL exceedances occurred at sites located in the LTL aquifer and the VRA aquifer; these exceedances are indicated in **Figure 4** by TDS levels in excess of 500 milligrams per liter (mg/l).

The 3 samples analyzed for pesticides had no detections for any of the 152 pesticides or degradation products on the ADEQ Groundwater Protection List.

Interpretation of these results suggest that groundwater in the VRGB supports drinking water uses. However residents, particularly those utilizing the LTL aquifer or the VRA aquifer, may prefer to install water treatment units for domestic use or to obtain domestic water from alternative sources for aesthetic reasons.

VI. Groundwater Composition

Groundwater in the VRGB may generally be described as *slightly alkaline*, *fresh* or *slightly saline*, and *hard* or *very hard* based on pH, TDS, and hardness levels, respectively. Trace elements such as aluminum, barium, beryllium, boron, cadmium, chromium, copper, lead, mercury, selenium, silver, and thallium were rarely detected. Only arsenic, fluoride, iron, manganese, and zinc were detected at more than 10 percent of the sites at concentrations above Arizona Department of Health Services Minimum Reporting Levels. Nutrients such as nitrate were, with a few exceptions, found at levels indicating minimal impact from human activities.

Groundwater chemistry is useful for illustrating differences in aquifers as well as tracing recharge sources within the basin. Each VRGB aquifer exhibits a characteristic water chemistry: calcium-bicarbonate in the BDW aquifer, calcium-sulfate in both the LTL aquifer and the VRA aquifer, and a mixed chemistry in the VRB aquifer. The groundwater chemistry of the BDW aquifer and the VRA aquifer seem strongly influenced by recharge from the surface water of Beaver Dam Wash and the Virgin River, respectively. Beaver Dam Wash exhibits a calcium-bicarbonate chemistry while the Virgin River has a calcium-sulfate chemistry.

The strength of association among levels of different parameters was assessed using Pearson's Correlation Coefficient test. Many significant (p# 0.05) correlations among parameter levels were detected. Positive correlations occur between TDS, specific conductivity (SC), major ions, total Kjeldahl nitrogen (TKN), boron, and to a lesser extent, iron and manganese. In contrast, these parameters had negative correlations with pH and nitrate. Fluoride had a unique pattern, positively correlated with only temperature, bicarbonate, calcium, and potassium. These findings are important because the levels of many salts and minerals at a sample site may be roughly gauged by obtaining an inexpensive parameter reading such as SC.

VII. Groundwater Quality Patterns

Significant (p# 0.05) statistical differences were detected between groundwater quality and aquifers using the Kruskal-Wallis test. Many parameter levels followed a typical aquifer pattern:

LTL > VRA > BDW >, =, < VRB

These differences in aquifer water quality are illustrated by graphically comparing hardness levels (**Figure 5**). The highest hardness levels are found in the LTL aquifer, its *very hard* water in evidence by the calcium carbonate precipitation on plumbing fixtures (**Figure 6**). Water in the VRA aquifer is also *very hard* but is significantly lower than water in the LTL aquifer. Although both have *hard* water, the BDW aquifer had significantly higher hardness levels than the VRB aquifer. Twelve (12) parameters generally followed this pattern: bicarbonate, boron, calcium, chloride, hardness, magnesium, potassium, sodium, SC, sulfate, total alkalinity, and TDS.

Figure 8. Situated in the Virgin River floodplain, a c
aquifer frames dormant riparian vegetation and the sn

Other significant (p# 0.05) patterns involved temperature, which was lower in aquifers (BDW and VRA) having direct contact with perennial surface flow than in those without direct surface flow (LTL and VRA) (**Figure 7**).

Figure 6. The red arrow points out the precipitation of calcium carbonate on a spigot as a result of *very hard* water pumped by a well tapping the LTL aquifer.

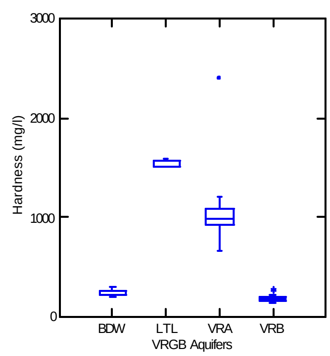

Figure 5. Boxplot comparing hardness levels among four VRGB aquifers.

Regression analysis reveals many parameters such as bicarbonate, calcium, chloride, hardness, magnesium, potassium, sodium, SC, sulfate, total alkalinity, and TDS significantly (p# 0.05) decreased with increasing groundwater depth below land surface. In contrast, nitrate, pH, temperature, turbidity, and zinc increased with increasing groundwater depth below land surface.

Despite these significant parameter level-groundwater depth relationships, data suggest that vertical variation is less important than spatial variation for parameters in the VRGB. Groundwater depth is significantly (p# 0.05) greater in the VRB aquifer than in the other aquifers sampled. Thus, groundwater depth patterns are likely influenced by spatial patterns. Other sources support this assertion and indicate that in Arizona, groundwater parameter levels tend to be a function of flow path evolution more than vertical mixing (5).

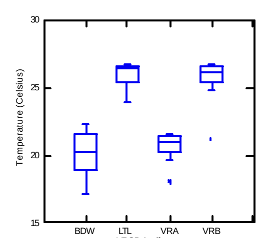

Figure 7. Boxplot comparing temperature levels among four VRGB aquifers.

A related analysis based on sampling results from three deep wells suggests that a deeper aquifer exists beneath two of the sampled aquifers. Two wells greater than 900 feet deep in the VRA aquifer and one well greater than 650 feet deep in the BDW aquifer had a dissimilar chemistry compared to nearby shallow wells. Calcium-sulfate groundwater with higher TDS levels is found below the shallow BDW aquifer while sodium-bicarbonate/chloride groundwater with lower TDS levels is found below the shallow VRA aquifer.

The deep BDW groundwater sample had many parameters exceeding the 95 percent confidence intervals established for the BDW aquifer. In contrast, two deep VRA groundwater samples had many parameters below the 95 percent confidence intervals established for the VRA aquifer. ***These findings tentatively suggest that for domestic or municipal use, relatively shallow wells should be used in the Beaver Dam area while deeper wells should be used near the Virgin River.***

VIII. Groundwater Impacts

To evaluate potential impacts to groundwater quality by human activities, upgradient control sample sites were compared to the 95 percent confidence intervals established for each VRGB aquifer. The results indicate that many parameter levels, including nitrate, in the control sites for the BDW aquifer and the LTL aquifer were often below the 95 percent confidence intervals. This indicates that the groundwater quality of these two aquifers might be affected by residential development impacts such as nitrates from septic systems used for wastewater treatment by many residents.

Although nitrate (as nitrogen) levels in the VRGB were generally below natural background levels of 3 mg/l, this parameter exhibits other unique patterns that warrant future monitoring. Based on statistical correlations, nitrate appears to originate from a different source than other groundwater quality parameters. A unique pattern also emerged in which nitrate levels in the LTL aquifer, which has little associated residential development, were significantly lower ($p \leq 0.05$) compared to the other three sampled aquifers.

IX. Groundwater Conclusions

Of the 38 sites sampled in the VRGB, 37 (97 percent) met health-based, water

quality standards but only 13 (34 percent) met aesthetics-based, water quality standards. Secondary MCL exceedances generally occurred at sites in the LTL aquifer and the VRA aquifer (**Figure 8**) while sites in the BDW aquifer and the VRB aquifer typically met Secondary MCL standards.

Each aquifer sampled in the VRGB has a unique groundwater composition which appears to be related to hydrological and geologic conditions within the basin. Surface water seems to be a major factor affecting groundwater quality in two aquifers. The relatively low parameter levels characteristic of the BDW aquifer are likely interconnected with the high-quality surface water in Beaver Dam Wash (2). Similarly, the relatively high parameter levels characteristic of the VRA aquifer are likely influenced by the saline surface flow of the Virgin River. Factors influencing the Virgin River salinity include an initial high salt concentration, saline spring discharges near the community of Littlefield, and irrigation return flows (2).

In contrast, the relatively low parameter levels characteristic of the VRB aquifer are likely the result of high-quality, mountain-front recharge from the Virgin Mountains. The relatively high parameter levels characteristic of the LTL aquifer appear to be influenced from contact with limestone known as the *Littlefield formation* (2). This horizontal limestone unit is overlain by alluvial fan deposits and is the likely cause of the saline, *very hard* groundwater found in the LTL aquifer.

---Douglas Towne
Maps by Larry W. Stephenson
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XI. References Cited

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